LEPA AND SPRAY IRRIGATION OF CORN—SOUTHERN HIGH PLAINS

A. D. Schneider, T. A. Howell

ABSTRACT. *Two LEPA and two spray sprinkler methods were evaluated with five irrigation amounts ranging from 0 to 100% of soil water replenishment in 25% increments. The LEPA methods were bubblers at the 0.3-m height and double-ended socks pulled through the furrows, and the spray methods were in-canopy spray at the 0.3-m height and overhead spray about 0.3 m above the mature crop canopy. The 100% irrigation treatment received 25-mm irrigations to maintain soil water at a non-yield-limiting level based on earlier research. Neutron soil water measurements verified the adequacy of the irrigation applications. Deficit irrigation treatments received 0, 25, 50, and 75% of the 25-mm irrigations on the same date. The field study was conducted on Pullman clay loam soil at Bushland, Texas, during the 1994 and 1995 crop years. Tillage, fertility, and weed and insect control were typical of those used for high-yield, on-farm corn production in the Southern High Plains. The corn was planted on 0.76-m spaced beds, all furrows were diked, and sprinkler devices were spaced 1.52 m apart over alternate furrows. Grain yields and seasonal water use efficiency (WUE) both increased significantly with irrigation amount. For 100% irrigation across the four sprinkler methods, grain yields and WUE averaged 13.5 Mg/ha and 1.68 kg/m^3, respectively. Significant differences in grain yields and WUE occurred among the sprinkler methods in 1994, but the yields and WUE were not consistently larger for either the LEPA or spray sprinkler method. In conclusion, both LEPA and spray are efficient sprinkler methods for irrigating corn for high grain yields in the Southern High Plains.* **Keywords.** *Irrigation, Sprinklers, Corn, LEPA, Spray, Efficiency.*

Irrigation is required for high-yield, economic corn production in the Southern High Plains. Musick and Dusek (1980) evaluated corn yield response to water deficits, water-yield functions and potential for limited irrigation in a three-year field study with level borders at Bushland, Texas. Corn irrigated for high yields produced 9.52 to 10.9 Mg/ha* with seasonal water use efficiency (WUE) of 1.25 to 1.46 kg/m^3. Their threshold seasonal evapotranspiration (ET) for initiating grain yield was approximately one half of the seasonal ET required for high yields. Because of corn's sensitivity to plant water stress, they concluded that "limited irrigation of corn should not be practiced". Eck (1984) evaluated corn yield response to both surface irrigation and nitrogen at Bushland, TX and obtained maximum grain yields ranging from 7.77 to 13.2 Mg/ha. Since surface irrigation was scheduled by stage of plant growth in the earlier studies, plant water stress likely prevented maximum grain yields in the fully irrigated treatments of Musick and Dusek (1980) and Eck (1984). In a three-year weighing lysimeter study with full season corn at Bushland, Texas, Howell et al. (1996) measured maximum daily ET rates exceeding 10 mm/day and seasonal ET ranging from 744 to 901 mm.

Sprinkler irrigation is now used extensively for corn production in the Southern High Plains. For fully irrigated corn, Howell et al. (1989) measured grain yield, ET, and WUE of 11.7 Mg/ha, 838 mm, and 1.40 kg/m^3, respectively. A 28-year CERES-Maize model simulation using calibration data from the study showed a net sprinkler capacity of 8 mm/day was needed to prevent irrigation constraints to yields. LEPA irrigation of corn has been studied by Howell et al. (1995) and Lyle and Bordovsky (1995). With full soil water replenishment, Howell et al. (1995) reported maximum grain yields ranging from 12.5 to 15.5 Mg/ha and seasonal ET ranging from 786 to 993 mm. Deficit irrigation with 60 and 80% of soil water replenishment resulted in WUE equal to or greater than with full irrigation but with correspondingly smaller grain yields. Lyle and Bordovsky (1995) used Base Irrigation (BI) Amounts (ET - Rainfall) of 0.4, 0.7, 1.0, and 1.3 to schedule LEPA irrigation of corn at 3, 6, 9, and 12-day intervals. Maximum grain yields of 15.1 Mg/ha occurred with the 1.3-BI irrigation level and three and six-day irrigation intervals. At the same BI, significant yield reductions to 14.4 and 14.0 Mg/ha occurred for 9 and 12-day irrigation intervals, respectively. Grain yields with 1.0 BI on 3 or 6-d intervals were similar to those with 1.3 BI on 9 or 12-day intervals. In the LEPA studies, deficit irrigation of corn was efficient when sprinkler irrigation was applied frequently and ET was above 50% of maximum ET.

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The authors are **Arland D. Schneider,** ***ASAE Member Engineer,*** Agricultural Engineer, and **Terry A. Howell,** ***ASAE Fellow Engineer,*** Research Leader (Agricultural Engineer), USDA-ARS, Bushland, Texas. **Corresponding author:** Arland D. Schneider, USDA-ARS, PO Drawer 10, Bushland, TX 79012; voice: (806) 356-5732; fax: (806) 356-5750; e-mail: aschneid@ ag.gov.

* All grain yields, water use efficiency and seed mass are reported at 15.5% moisture content based on wet weight.

Recent sprinkler evaporation studies suggest smaller evaporation losses from sprinkler and spray irrigation than was suggested by the earlier work of Christiansen (1942) and Frost and Schwalen (1960). A laboratory study by Kincaid and Longley (1989) illustrated, that for the high evaporative environment of 31°C and 22% relative humidity, the evaporation rate from 1.0-mm diameter droplets would not exceed 1% of the mass per second. Solomon et al. (1985) showed that the average droplet size from serrated plates exceeds 1.0 mm. With in-air times less than 1 s, air evaporation losses from serrated spray plates would then be on the order of 1%. This estimate is supported by Kohl et al. (1987) who measured low-pressure sprinkler losses of 0.5 to 1.4% from smooth spray plates and 0.4 to 0.6% from coarse, serrated spray plates. Modeling studies by Thompson et al. (1993) and Thompson et al. (1997) showed total droplet evaporation losses of 3% from a solid set sprinkler system and 1% from a moving lateral irrigation system. For a mature corn canopy, Tolk et al. (1995) showed that transpiration suppression due to evaporation of canopy-intercepted water and microclimate modification resulted in net canopy evaporation losses of only 5.1 to 7.1%.

In this study, we compared two LEPA and two spray sprinkler methods for corn in the Southern High Plains with full irrigation, three deficit irrigation amounts and a non-irrigated treatment.

PROCEDURE

The research was conducted at the USDA Conservation and Production Research Laboratory, Bushland, Texas (35°11′ N lat, 102°06′ W long, 1170 m msl elevation), during the 1994 and 1995 corn seasons. The Pullman clay loam soil at the site is a fine, mixed, *Thermic Torrertic Paleustoll* with a dense B21t subsoil from about 150 to 400 mm and a calcic horizon extending from the 1.5 to 2.0-m depths. For the upper 1.47-m profile, Unger and Pringle (1981) measured 167 mm of soil water between the −0.033 and −1.5 MPa water potentials. The research field had a uniform slope of 0.0025 m/m along the furrows and 0.0022 m/m perpendicular to the furrows.

EXPERIMENTAL DESIGN

Two LEPA and two spray sprinkler methods were evaluated with five irrigation amounts ranging from 0 to 100% of soil water replenishment in 25% increments. The irrigation amounts are designated as I_0, I_{25}, I_{50}, I_{75}, and I_{100}, respectively. The LEPA sprinkler methods were double-ended socks and bubblers designated as M_1 and M_2, respectively, and the spray sprinkler methods were in-canopy and overhead spray designated as M_3 and M_4, respectively. Field plots were arranged in a randomized block design with irrigation amount treatments being the blocks and sprinkler methods being randomized within each block. The 20 treatment combinations were replicated three times, once under each span of the irrigation system. Plot size was twelve 0.76-m rows wide along the pipeline of the lateral move irrigation system by 25 m long in the direction of travel.

Soil water was measured gravimetrically on all plots for determining seasonal soil water depletion and with a neutron meter on the I_{100} plots for scheduling irrigations. Gravimetric samples were collected in 0.30-m increments to the 1.8-m depth after planting and at harvest. Neutron soil water samples were collected with a locally field-calibrated CPN Model 503DR neutron moisture meter (Evett and Steiner, 1995). Weekly measurements were made in 0.2-m increments to the 2.4-m depth except when rainfall made irrigation unnecessary. The gravimetric and neutron soil water measurements were both collected in one of the two center rows of the 12-row wide plots.

IRRIGATION EQUIPMENT

Irrigations were applied with a three-span, hose-fed Valmont Model 6000 lateral move irrigation system supplied with pressurized water from a surface reservoir. Each span was 39 m long and provided space for forty-eight, 0.76-m wide beds and furrows. Both the LEPA and spray devices were spaced 1.52 m apart to apply water into or above alternate furrows. The LEPA double-ended socks, M_1, were attached to Senninger Super Spray heads and pulled through the furrows with the full length of the sock in contact with the ground. Senninger Quad IV spray heads, positioned about 0.3 m above the furrow bottom, were used for the LEPA bubble method, M_2, and the in-canopy spray method, M_3. Nelson Spray I spray heads with convex, medium-grooved deflector plates were positioned about 0.3 m above the height of the mature corn canopy for the overhead spray method, M_4. The Senninger and Nelson sprinkler devices were regulated with 41- and 69-kPa pressure regulators and discharged through 6.75- and 5.95-mm nozzles, respectively. Irrigation amount was varied by varying the speed of the lateral move irrigation system.

CULTURAL PRACTICES

Cultural practices were similar to those used for high-yield, sprinkler-irrigated corn in the Southern High Plains. Table 1 lists fertility, pesticide, crop variety, and plant population information plus planting and harvesting dates for the two crop years. Both crops were grown on land that had been fallowed with sweep or disk tillage during the previous year to accumulate soil water and hopefully to reduce weed, soil-borne disease and insect populations.

All tillage and planting was done with six-row farm machinery to fit the 48-row-wide spans of the irrigation system. After application of anhydrous ammonia fertilizer during the early spring (table 1) the plot area was tandem disked and bedded with a disk bedder. Rainfall during March 1994 insured a firm seedbed, but in the dry spring of 1995, the beds were packed with one pass of a rolling cultivator and one pass of a cultipacker. Planting was with

Table 1. Agronomic and seasonal irrigation data for the two corn crops

Variable	1994	1995
Fertilizer applied on I_{100}	80 kg(N)/ha preplant 100 kg(N)/ha with irrigation 110 kg(P)/ha preplant	110 kg(N)/ha preplant 90 kg(N)/ha with irrigation 110 kg(P)/ha preplant
Herbicide applied	Atrazine 1.70 kg(AI)/ha	Atrazine 1.70 kg(AI)/ha
Insecticide applied	Capture 0.09 kg/ha Dimethoate 0.56 kg/ha	None
Corn variety	Pioneer 3245	Pioneer 3162
Planting date	14 April	28 April
Harvesting date	12-16 Sept	29 Sept
Plant population (plants/m²)	7.05	8.20

a John Deere Max-Emerge planter. The corn was cultivated once at the 0.2- to 0.3-m height with a rolling cultivator, and all furrows were then diked with a Bigham Brothers trip and roll diker. During the 12-leaf to silking stages of plant growth, nitrogen was applied in the irrigation water in proportion to the depth of irrigation (table 1).

Grain yields were measured by hand harvesting 6.6 m of the two center rows in each plot to obtain a 10 m^2 sample area. The grain samples were dried to 0% water content, weighed for yield determination and 1000 seed from each sample were weighed to obtain the average seed mass.

Irrigation Procedure

With the corn being planted on fallowed land, preseason irrigation for seed germination and crop establishment was either small or not needed. Preseason irrigation was not required in 1994, but the 1994-1995 winter and spring were exceptionally dry, and 44 mm of preplant irrigation was applied to the entire experimental area during 19-21 April 1995. The 1994 crop received a 30-mm emergence irrigation on 18 April, and the 1995 crop received a 20-mm emergence irrigation on 1 May followed by an 8-mm irrigation on 9 May. All preseason and emergence irrigation was applied with overhead spray to obtain crop emergence with the minimum amount of irrigation water. The first seasonal irrigation was also applied with the overhead spray method to settle the soil in the furrow dikes before LEPA irrigating.

The dates and amounts of seasonal irrigation to the I_{100} irrigation treatments are illustrated in figure 1. Irrigations were scheduled to maintain soil water in the I_{100}/M_1 treatment at 90% of the plant available amount. This is about 466 mm total soil water in the upper 1.5-m profile. Twenty-five millimeter seasonal irrigations were normally applied to the I_{100} plots, and the deficit-irrigated treatments received 0%, 25%, 50% and 75% of the fully irrigated amount on the same day.

Seasonal water use efficiency (WUE) and irrigation water use efficiency (IWUE), both reported as kg/m^3, will be used to evaluate the efficiency of the irrigation amounts and sprinkler methods. WUE will be reported as grain yield divided by seasonal evapotranspiration, and IWUE will be reported as irrigated grain yield minus non-irrigated grain yield divided by irrigation amount.

Results and Discussion

Cumulative growing season rainfall is illustrated in figure 1 for the two corn seasons, and minimum and maximum daily temperatures are illustrated in figure 2. These two climatic variables have the largest effect on corn yields in the Southern High Plains. Growing season rainfall in 1994 started near average (fig. 1), dropped to about 100 mm below average in early July and then ended the growing season near average. Rainfall in 1995 was below average the entire growing season, and the cumulative deficit was about 125 mm at crop maturity in late-August. In 1994, early summer temperatures were above average until early July, and then, the trend reversed with many late-summer daily temperatures below average. In 1995, the seasonal temperature trend reversed with most early-summer temperatures below average and most late-summer temperatures above average. The most extreme temperature event for the two years was the low temperature in late-April 1994 but this did not adversely affect the crop. The above average late-July 1995 temperatures appeared to adversely affect pollination and reduce seed set of the crop.

Seasonal irrigation amounts and distribution, illustrated in figure 1, show the influence of planting dates and temperature and rainfall trends. Seasonal irrigation started about two weeks earlier in 1994 because of the two-week earlier planting date. Above-average temperatures and below-average rainfall from late-May until early July 1994 caused the growing season irrigation to be concentrated during that interval. With favorable rainfall and cooler temperatures after mid-July, irrigation was less frequent and could be terminated after 22 August. Twenty-one seasonal irrigations were applied with seasonal totals of 128, 257, 385, and 513 mm to I_{25}, I_{50}, I_{75}, and I_{100}, respectively. With continual below-average rainfall in 1995, irrigation was distributed throughout the growing season. Irrigation was most frequent during the above-average temperatures in late-July and was not terminated until 4 September. Twenty-two seasonal irrigations were

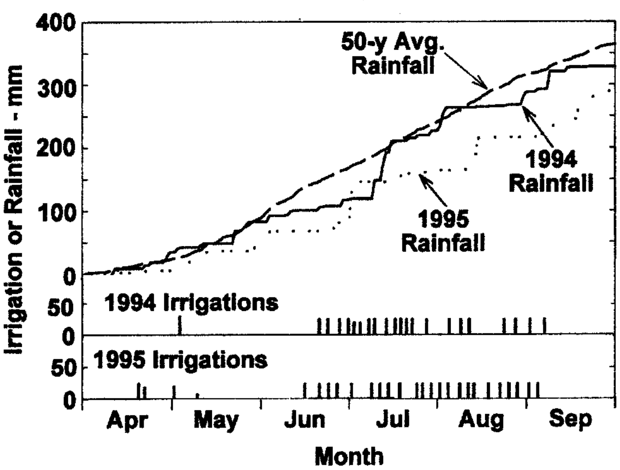

Figure 1–The 1994 and 1995 irrigation amounts and corn growing season rainfall at Bushland, Texas, for 1994 and 1995 and the 50-year average.

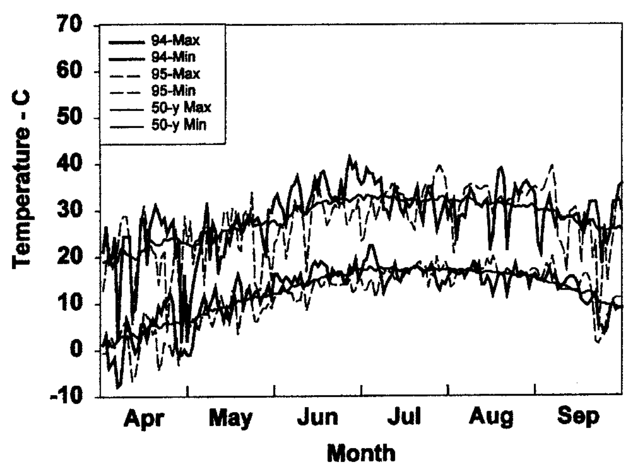

Figure 2–Minimum and maximum temperatures at Bushland, Texas, for 1994 and 1995 and the 50-year average.

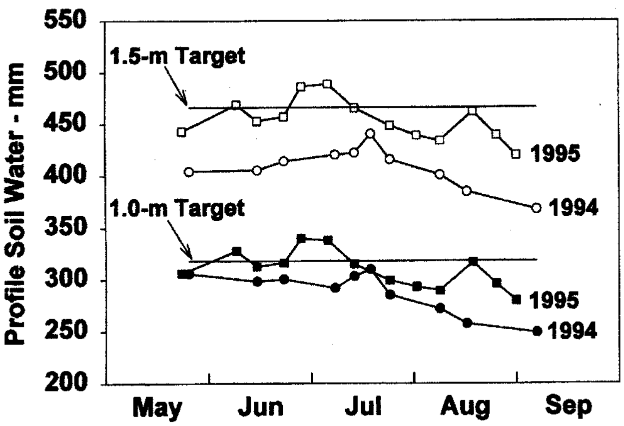

Figure 3–Soil water in the 1.0- and 1.5-m soil profiles of the I_{100}/M_1 treatment and the target levels of 318 and 466 mm for the two respective depths.

applied with seasonal totals of 138, 275, 413, and 550 mm to I_{25}, I_{50}, I_{75}, and I_{100}, respectively.

Soil water in the upper 1.0-m and 1.5-m profiles of the I_{100}/M_1 treatment is illustrated in figure 3 for the two growing seasons. In 1994, soil water was near the target amount until late-July. After that, it declined slowly until the 22 August irrigation cutoff date, and then declined more rapidly until the last measurement on 6 September. Soil water in 1995 was at or near the target level until 13 July, then declined slightly before returning to the target level on 18 August and finally declined 37 mm by the last sampling date on 31 August.

Table 2. Grain yield, seasonal soil water depletion, ET, water use efficiencies and seed mass for 1994

Irrigation Amount	Sprinkler Method	Grain Yield (Mg/ha)	Soil Water Depl. (mm)	ET* (mm)	WUE (kg/m³)	IWUE (kg/m³)	Seed Mass (mg/kernel)
0%		0	58	337	0		0
25%	LEPA sock	4.60	96	500	0.92	3.68	184
	LEPA bubble	3.13	102	506	0.62	2.51	182
	In-canopy spray	2.65	91	495	0.54	2.12	196
	Overhead spray	3.38	61	465	0.73	2.71	188
50%	LEPA sock	9.59	52	581	1.65	3.84	227
	LEPA bubble	8.32	83	612	1.36	3.33	224
	In-canopy spray	7.89	75	604	1.31	3.16	237
	Overhead spray	8.15	79	608	1.34	3.26	224
75%	LEPA sock	10.96	61	715	1.53	2.92	239
	LEPA bubble	9.32	66	720	1.29	2.48	225
	In-canopy spray	11.69	78	732	1.60	3.12	249
	Overhead spray	11.74	76	730	1.61	3.13	252
100%	LEPA sock	12.09	52	831	1.46	2.42	257
	LEPA bubble	12.56	41	820	1.53	2.51	269
	In-canopy spray	14.36	39	818	1.76	2.87	281
	Overhead spray	14.79	35	814	1.81	2.96	287
	Irrigation Amount Averages						
0%		0e†	58	337	0d		0e
25%		3.44d	87	491	0.70c	2.76b	187d
50%		8.49c	72	601	1.42b	3.40a	228c
75%		10.92b	71	725	1.51b	2.91b	241b
100%		13.45a	42	821	1.64a	2.69b	273a
	Sprinkler Method Averages						
	LEPA sock	7.45a	60	589	1.11a	3.32a	181bc
	LEPA bubble	6.67b	73	602	0.96b	2.71c	180c
	In-canopy spray	7.32ab	70	599	1.04ab	2.82bc	193a
	Overhead spray	7.61a	66	595	1.10a	3.01ab	190ab

* Includes 279 mm of growing season precipitation.
† Averages followed by the same letter are not significantly different ($p \leq 0.05$).

Table 3. Grain yield, seasonal soil water depletion, ET, water use efficiencies, and seed mass for 1995

Irrigation Amount	Sprinkler Method	Grain Yield (Mg/ha)	Soil Water Depl. (mm)	ET* (mm)	WUE (kg/m³)	IWUE (kg/m³)	Seed Mass (mg/kernel)
0%		0	55	293	0		0
25%	LEPA sock	0	71	446	0	0	0
	LEPA bubble	0	63	439	0	0	0
	In-canopy spray	0	74	449	0	0	0
	Overhead spray	0	90	466	0	0	0
50%	LEPA sock	7.67	49	562	1.36	2.79	283
	LEPA bubble	7.78	34	547	1.42	2.83	283
	In-canopy spray	8.93	37	550	1.62	3.25	291
	Overhead spray	7.40	61	574	1.29	2.69	275
75%	LEPA sock	13.01	39	690	1.89	3.15	332
	LEPA bubble	13.14	47	697	1.88	3.19	328
	In-canopy spray	10.59	43	694	1.53	2.57	305
	Overhead spray	11.33	56	707	1.60	2.75	304
100%	LEPA sock	13.43	66	838	1.60	2.44	315
	LEPA bubble	14.29	8	772	1.85	2.60	333
	In-canopy spray	12.63	1	765	1.65	2.30	312
	Overhead spray	13.79	46	796	1.73	2.51	322
	Irrigation Amount Averages						
0%		0d†	55	293	0c		0c
25%		0d	75	450	0c	0c	0c
50%		7.94c	45	558	1.42b	2.89a	283b
75%		12.02b	46	697	1.73a	2.91a	317a
100%		13.54a	30	793	1.71a	2.46b	321a
	Sprinkler Method Averages						
	LEPA sock	6.82a	56	565	0.97a	2.10a	186a
	LEPA bubble	7.04a	39	547	1.03a	2.15a	189a
	In-canopy spray	6.43a	41	549	0.96a	2.03a	182a
	Overhead spray	6.50a	66	571	0.92a	1.99a	180a

* Includes 238 mm of growing season precipitation.
† Averages followed by the same letter are not significantly different ($p \leq 0.05$).

Grain Yields

Grain yields are listed in tables 2 and 3 for all 20 treatments and for the irrigation amount and sprinkler method averages. Grain yield increased significantly with irrigation amount ($p \leq 0.01$) during both years. In 1994, there was no grain yield with I_0. In 1995 with below-average rainfall and above-average temperatures during pollination, there was no grain yield with either I_0 or I_{25}. The I_{25} to I_{50} irrigation increment resulted in the largest yield increases of 5.05 Mg/ha in 1994 and 7.94 Mg/ha in 1995. Further significant yield increases occurred for the two larger irrigation amounts. In 1994 grain yield with the LEPA bubble was significantly less than with the LEPA sock and overhead spray ($p \leq 0.05$), but it did not vary significantly from the in-canopy spray. In 1995, no significant yield differences occurred among the four sprinkler methods ($p \leq 0.05$). There were no consistent interactions between irrigation amount and sprinkler method during the two years.

Seed mass increased significantly with each irrigation increment in 1994 and for the I_{50} to I_{75} irrigation increment in 1995. The close correlation between grain yield and seed mass illustrates the importance of high seed mass in achieving high grain yields. For the sprinkler methods, there were some significant differences in seed mass in 1994 but none in 1995.

Grain yield as a function of seasonal water use during both years is illustrated in figure 4. The linear equation, $GY = 0.0296(ET - 341)$ indicates a 341-mm threshold ET for grain production and 2.96 kg of grain per cubic meter of water for ET exceeding 341 mm. Comparison with other reported research shows the present data to be in the mid-

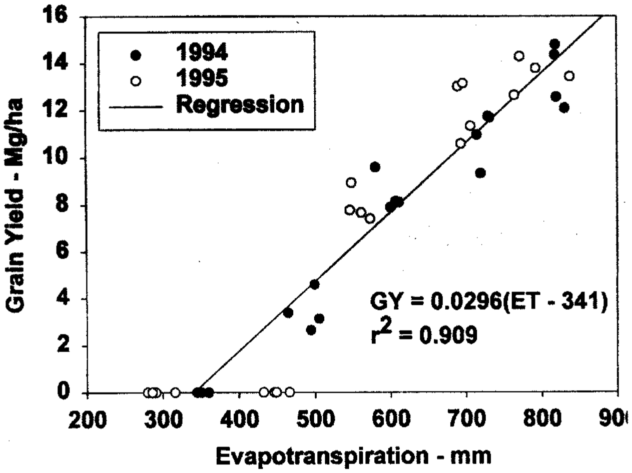

Figure 4–Grain yield as a function of evapotranspiration for the two corn crops.

range of production coefficients for the Southern High Plains:

GY = 0.028(ET – 263)	Howell et al., 1997	Drip irrigated
GY = 0.020(ET – 147)	Howell et al., 1995	LEPA sprinkler irrigated
GY = 0.048(ET – 328)	Lamm et al, 1995	Drip irrigated
GY = 0.034(ET – 467)	Howell et al., 1989	Impact sprinkler irrigated
GY = 0.024(ET – 346)	Musick and Dusek, 1980	Basin irrigated

The slopes range from a low of 0.20 with LEPA sprinkler irrigation to a high of 0.48 with drip irrigation. Since these equations account for the threshold ET to initiate grain production, the slopes may be a better indication of physiological water use efficiency than simple GY/ET ratios such as WUE or IWUE.

Water Use Efficiency

Seasonal and irrigation water use efficiencies are listed in tables 2 and 3 for the two cropping years. Water use efficiency ranged from 0 to 1.73 kg/m^3 during the two cropping years, and differences increased significantly with irrigation amount. The largest WUE were 1.64 kg/m^3 with I_{100} in 1994 and 1.73 kg/m^3 with I_{75} in 1995. WUE varied significantly among the sprinkler methods in 1994, but not in 1995. IWUE as defined here illustrates the efficiency of the irrigation water portion of seasonal water use or ET. The largest IWUE of 3.40 kg/m^3 in 1994 and 2.91 kg/m^3 in 1995 occurred with an intermediate level of deficit irrigation. IWUE then decreased significantly as irrigation increased to the I_{100} amount. For the sprinkler methods, IWUE followed the same trend as WUE with some significant differences in 1994 but none in 1995.

The water use efficiency values from this study indicate efficient use of both seasonal ET and irrigation water for corn production in the Southern High Plains. With basin irrigation for high yields, Musick and Dusek (1980) reported WUE values ranging from 1.25 to 1.46 kg/m^3. Howell et al. (1989) reported WUE values with impact sprinkler irrigation ranging from 0.96 to 1.40 kg/m^3. The I_{75} and I_{100} water use efficiencies ranging from 1.51 to 1.73 kg/m^3 are similar to those reported by Howell et al. (1989) for LEPA irrigation and by Howell et al. (1997) for surface and subsurface drip irrigation. The I_{50} and I_{100} irrigation water use efficiencies ranging from 2.89 to 3.40 kg/m^3 are also comparable to those reported by Howell et al. (1989) for LEPA irrigation. They are smaller, however, than the 3.55 to 5.27 kg/m^3 values reported by Lyle and Bordovsky (1995) for comparable levels of irrigation.

Conclusions

In the Southern High Plains, corn is highly dependent on irrigation for both high yields and efficient water use. Although there were some significant differences among sprinkler methods during one year, there was no clear advantage to using either the LEPA or spray sprinkler methods to apply the irrigation water. The largest seasonal water use efficiencies occurred at or near the 100% irrigation amount, and the largest irrigation water use efficiencies occurred with the 50 or 75% irrigation amounts.

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